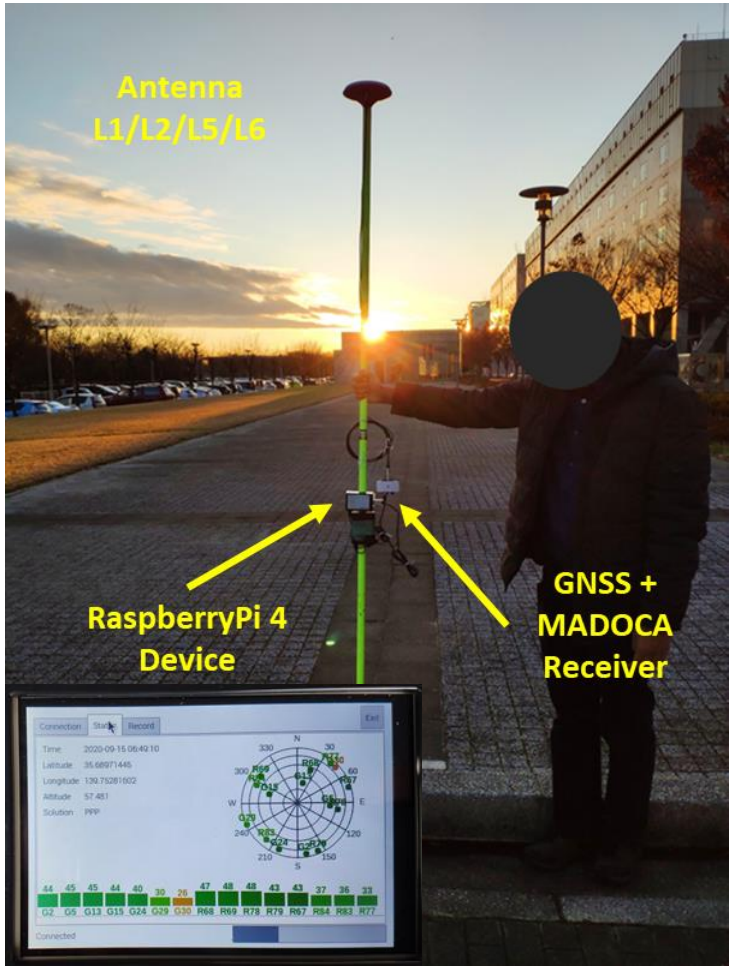
Low-Cost High-Accuracy GNSS Receiver Systems
(A) Based on RTK/PPK
(B) Based on MADOCA



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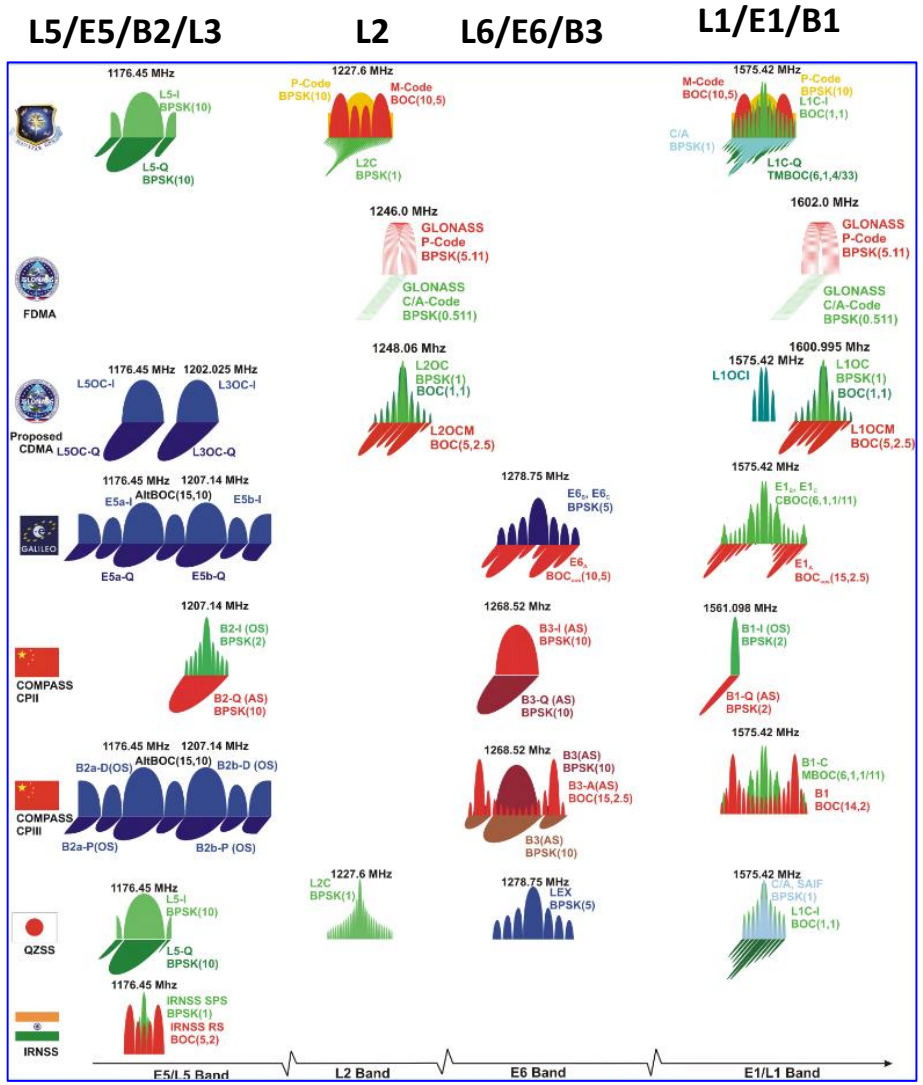
28th January 2021

Quiz

- What is the Price of a GNSS Receiver?
  - $10? / $100? / $500 / $1,000 / $3,000 / $10,000 or more?
- What is the Accuracy that you can get from a GNSS receiver?
  - mm, cm, dm, few meters or 10 – 30m
- But, what are your requirements?
  - Types of Applications
  - Accuracy Requirements
  - Data Logging Methods
    - Static Mode on a Tripod
    - Dynamic Mode on a Car, Tractor or Machine?
  - Real-Time or Post-Processing

High-End Survey Grade Receivers

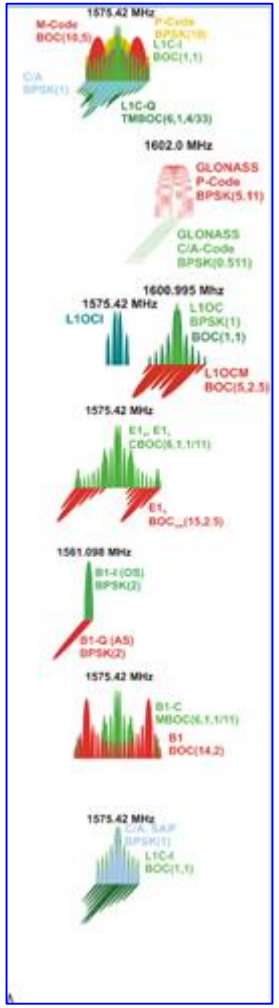
- Multi-frequency
  - GPS : L1/L2/L5
  - GLONASS : L1/L2/L3
  - GALILEO : E1/E5/E6
  - BDS : B1/B2/B3
  - QZSS : L1/L2/L5/L6
  - NAVIC : L5/S
- Multi-system
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC, SBAS etc
- Price varies from $3, 000 to $30,000 or more



Low-Cost Receivers

- Multi-System
  - GPS, GLONASS, GALILEO, BeiDou, QZSS, SBAS etc
- Basically Single Frequency
  - L1/E1/B1-Band
  - Very soon: Multi-System, Multi Frequency, L1/L2 or L1/L5
    - Future trend for Mass Market System will be L1/L5
  - Some chip makers have already announced Multi-System, Multi-Frequency GNSS Chips for Mass Market
- Low Cost:
  - Less than $300 (Multi-GNSS, L1 Only) including Antenna and all necessary Hardware, Software
    - Our target is within $100 or less including everything

L1/E1/B1*



*Note: Only one signal type from each system is processed
e.g. GPS has L1C/A and L1C in L1, ,but only L1C/A is used in Low-Cost Receiver

Our Definition of Low-Cost Receiver

- Price : $100 or less
- Accuracy : Better than 100cm
- Weight : 100g or less
  (Without Battery)

$$100^3$$

$100 x 100cm x 100g

Will it be possible?

Many Applications require
Low-Cost, Small-Size & Low-Power
Receiver System

But, is it possible to get
High-Accuracy with Low-Cost Receivers?

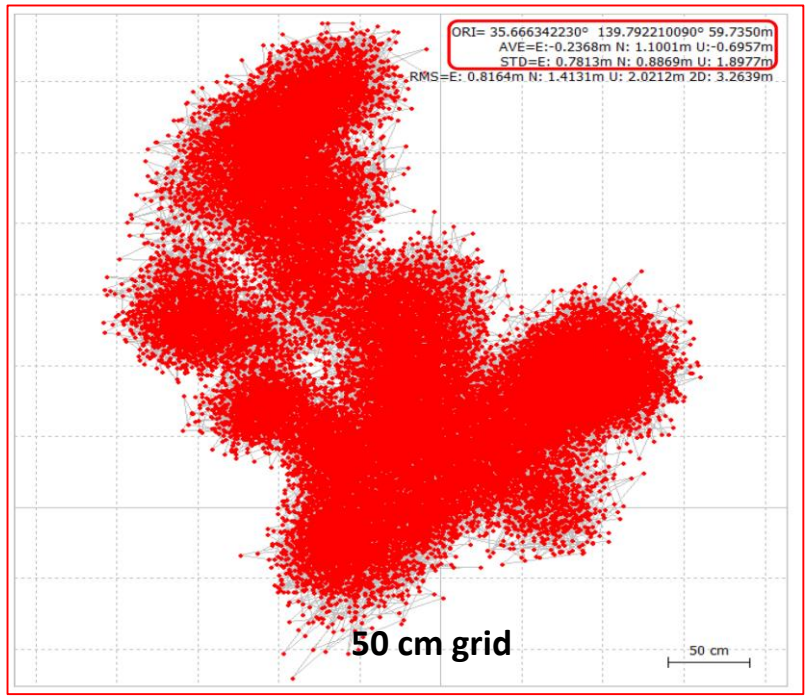
Question?

Although the Normal Accuracy of GPS is about 10m,
why can we get Centimeter Level Accuracy?

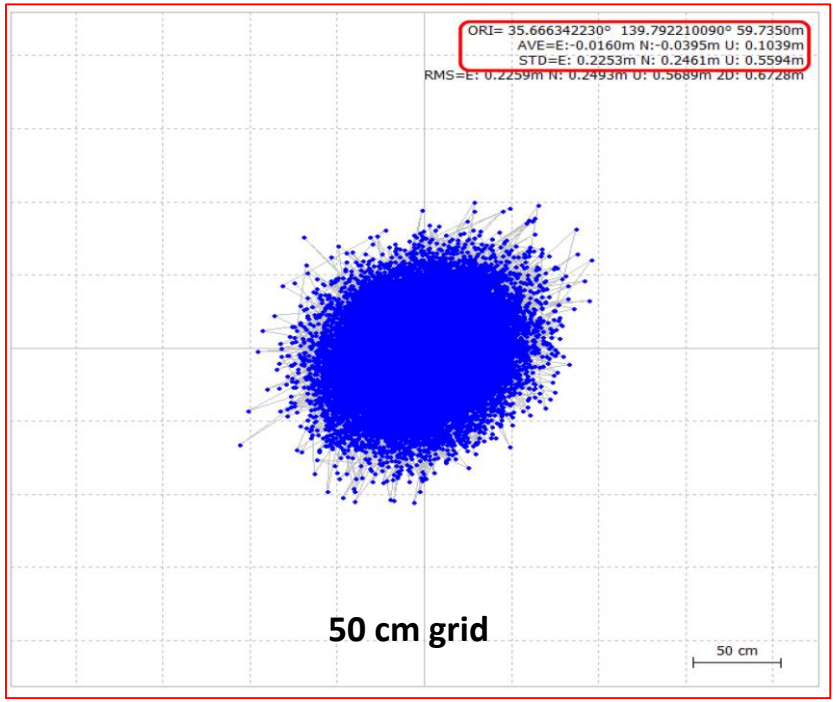
GPS Position Accuracy

How to achieve accuracy from few meters to few centimeters?

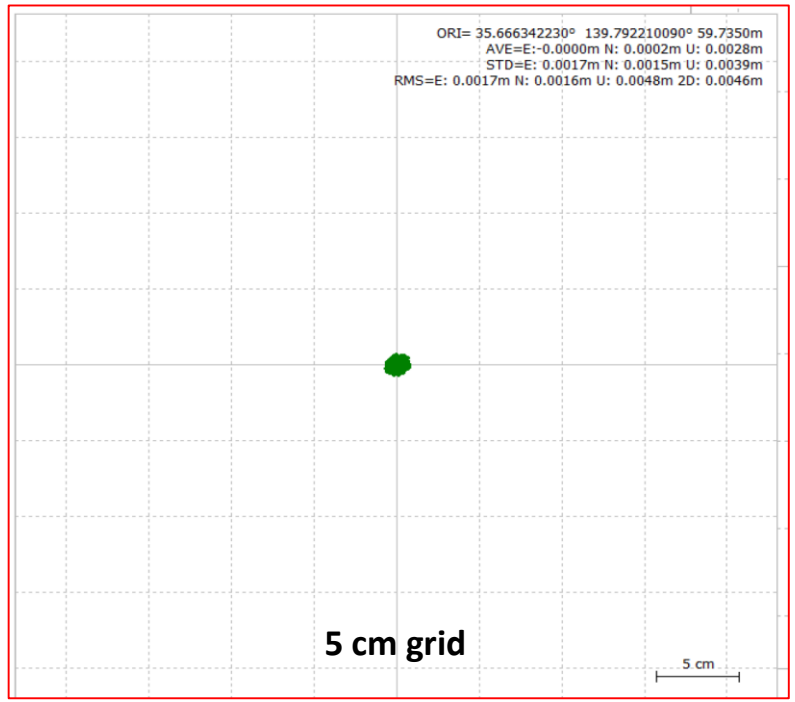
meter → centimeter



SPP (Single Point Position)



DGPS (Differential GPS)
Code-phase observation



RTK (Real Time Kinematic)
Carrier-phase observation

Errors in GPS Observation (L1C/A Signal)

Error Sources	One-Sigma Error , m		Comments
	Total	DGPS	
Satellite Orbit	2.0	0.0	Common errors are removed
Satellite Clock	2.0	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

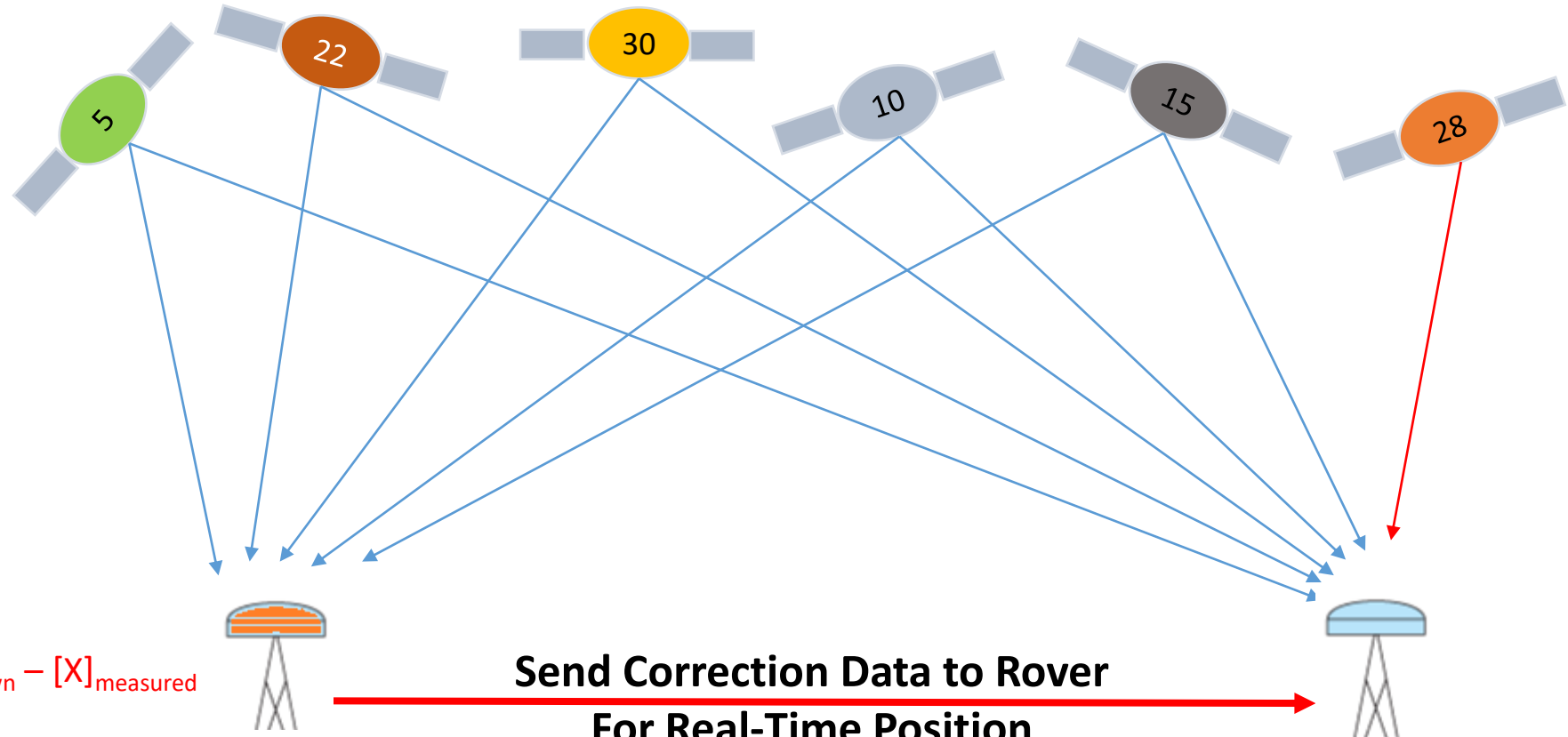
If we can remove common errors, position accuracy can be increased.

Common errors are: Satellite Orbit Errors, Satellite Clock Errors and Atmospheric Errors (within few km)

Values in the Table are just for illustrative purpose, not the exact measured values.
Table Source : http://www.edu-observatory.org/gps/gps_accuracy.html#Multipath

How to Remove or Minimize Common Errors?

Use Differential Correction



$[X]_{error} = [X]_{known} - [X]_{measured}$

Send Correction Data to Rover

For Real-Time Position

For RTK, both rover and base receivers need to use the same satellites

Base-Station

Antenna is installed at a known-position

Base-station Antenna position shall be known in advance

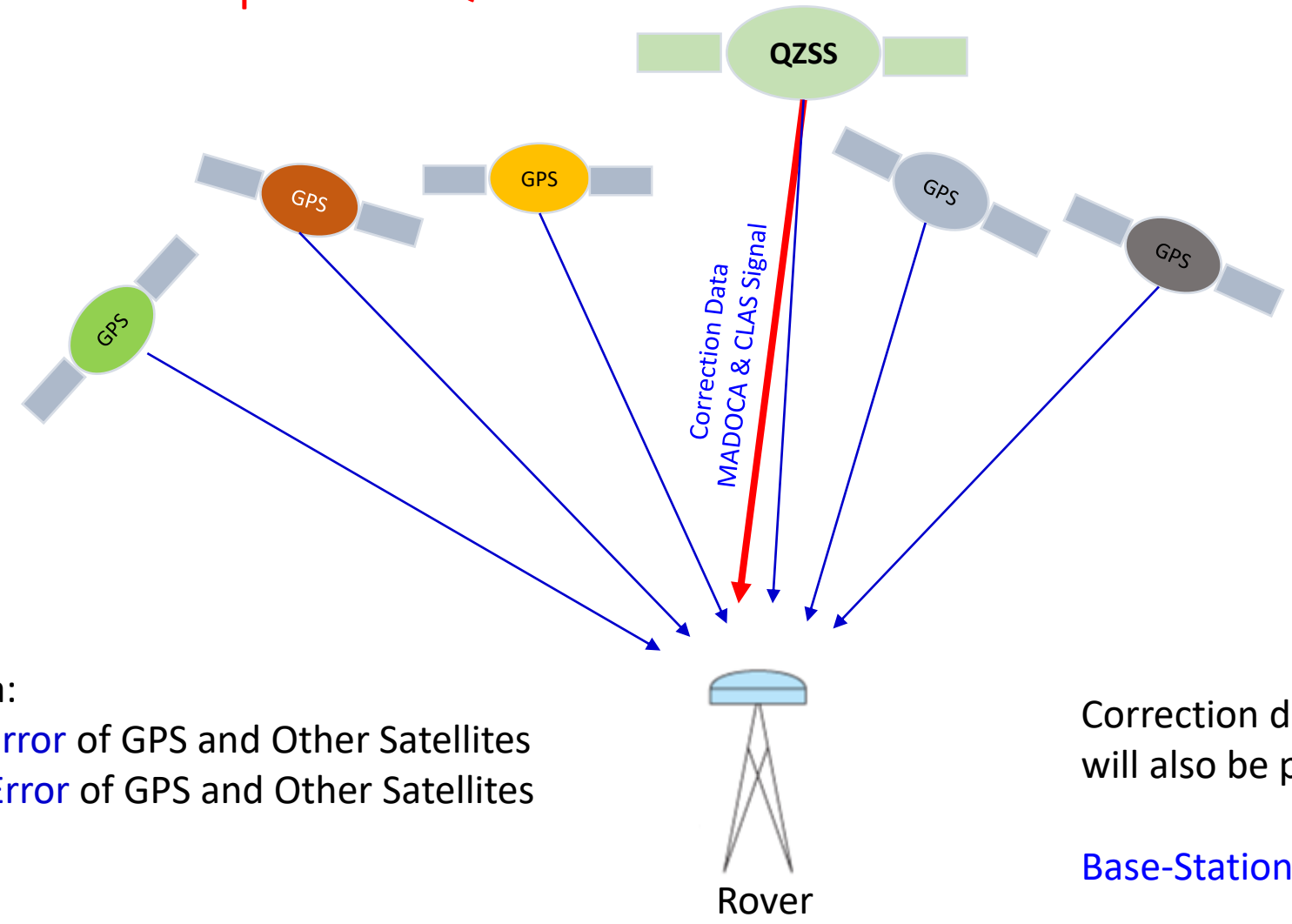
Rover

User in the Field

(Either fixed or moving)

How to Remove or Minimize Common Errors?

Principle of QZSS MADOCA and CLAS Services



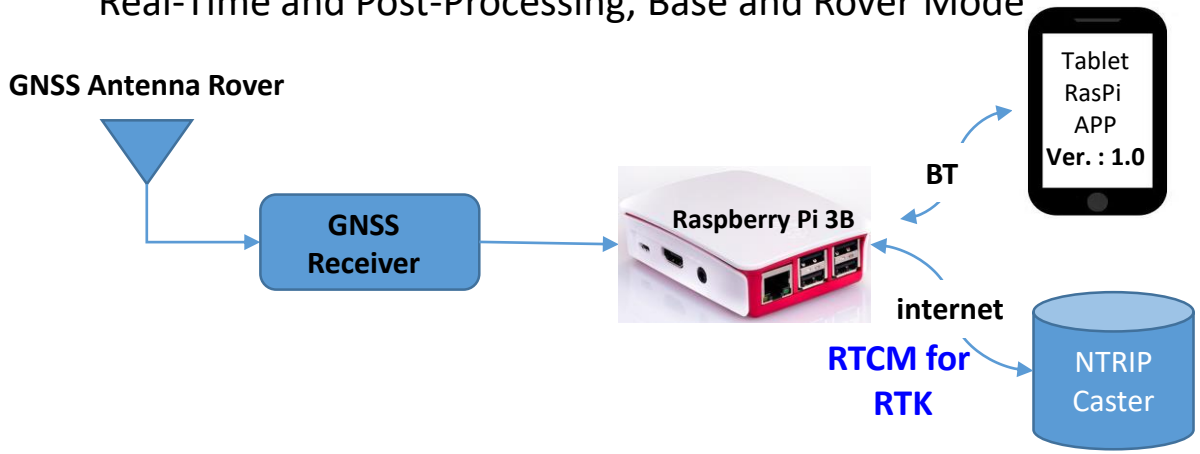
Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

Correction data for other satellites will also be provided

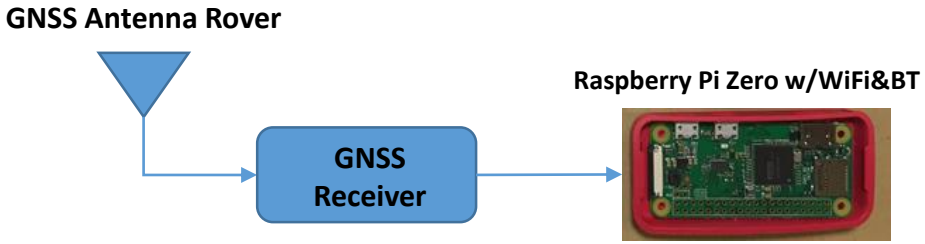
Base-Station not required

Low-Cost RTK Receiver System

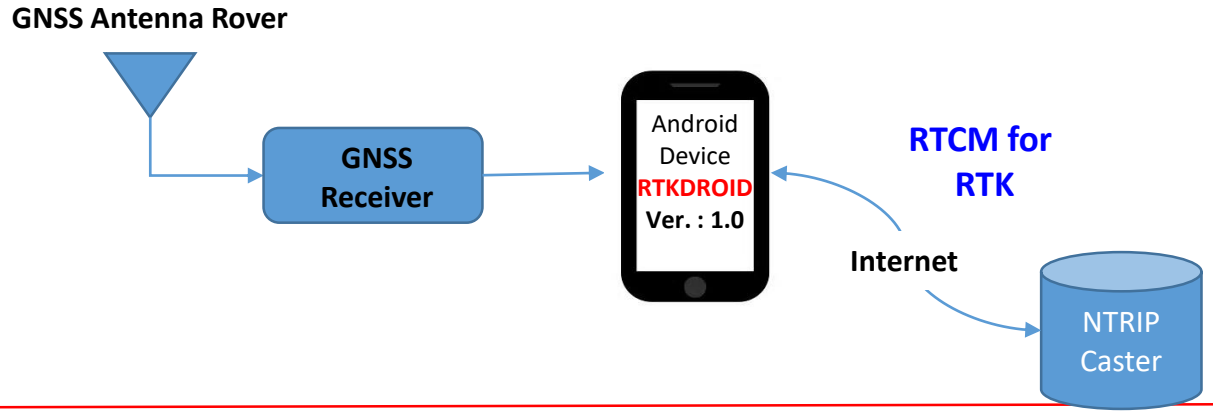
TYPE R1 Type A: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Base and Rover Mode



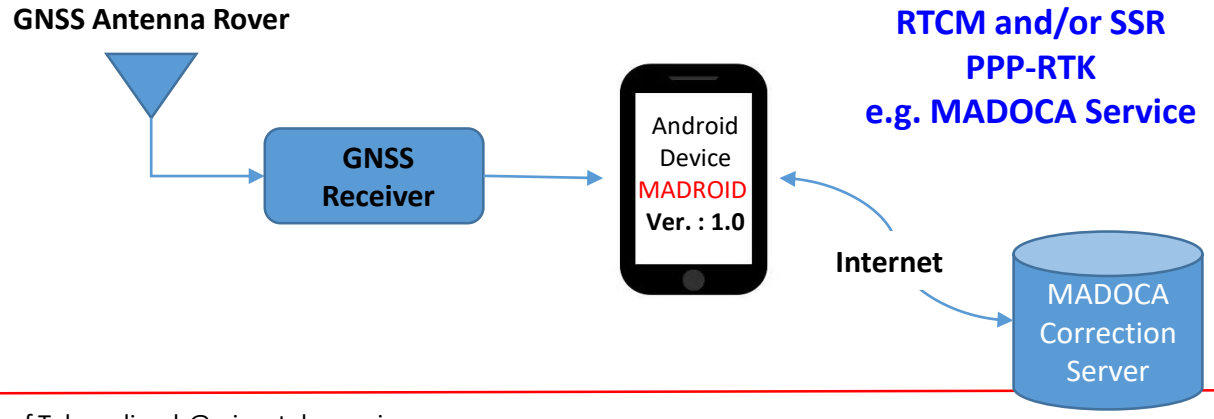
TYPE R2 Type B: Low-Cost, High-Accuracy Receiver System
For Post-Processing & Rover Mode Only



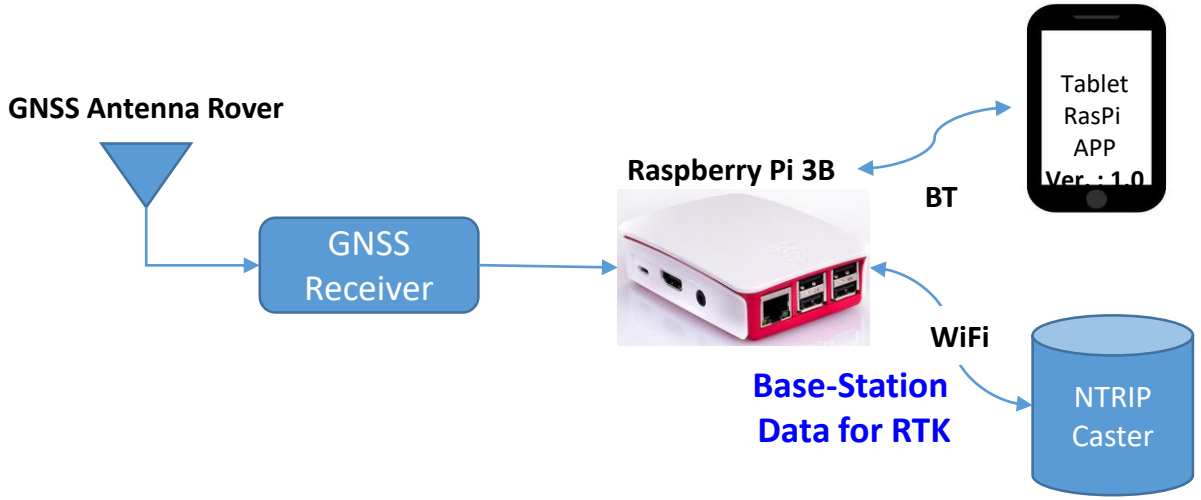
TYPE A1 Type C: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only



TYPE MA Type D: Low-Cost, High-Accuracy Receiver System
Real-Time and Post-Processing, Rover Mode Only

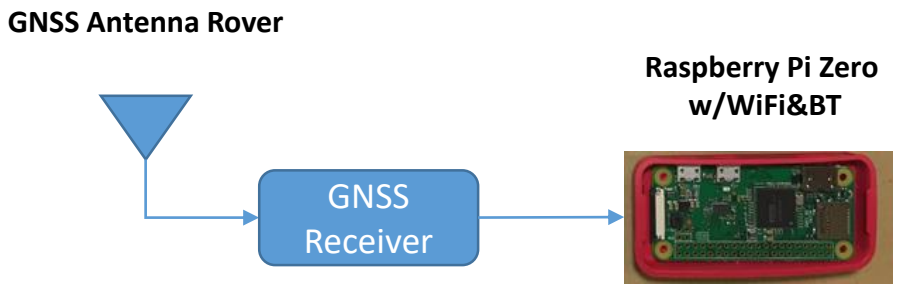


Type – R1: GNSS Receiver with RaspberryPi-3B



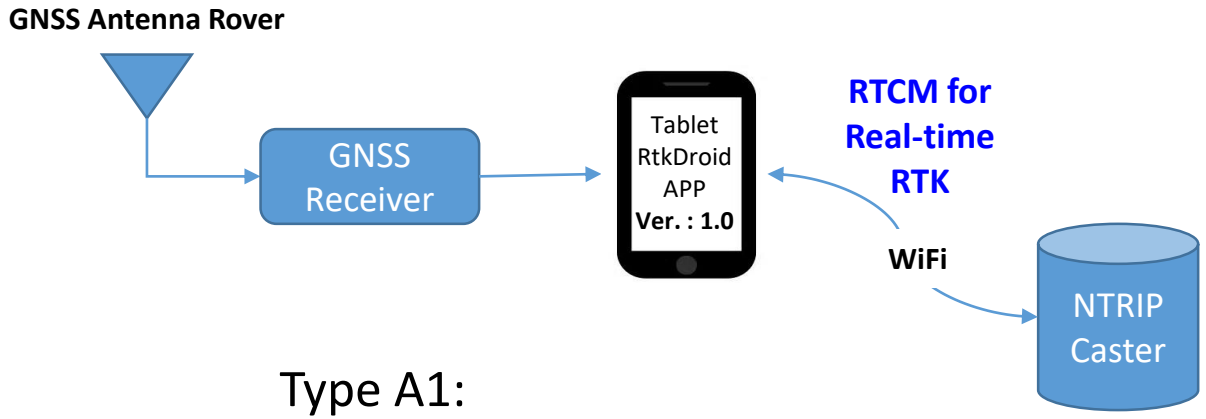
Type R1:
Base or Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine

Type – R2: GNSS Receiver with RaspberryPi-Zero/W



Type R2:
Rover Mode
Post-Processing RTK
Log Necessary Raw Data for Post-processing RTK
Based on RTKLIB Engine

Type – A1: GNSS Receiver with Android Device



Type A1:
Rover Mode
Real-Time and Post-Processing RTK
Based on RTKLIB Engine
Real-time processing in Android Device
APP: RTKDroid

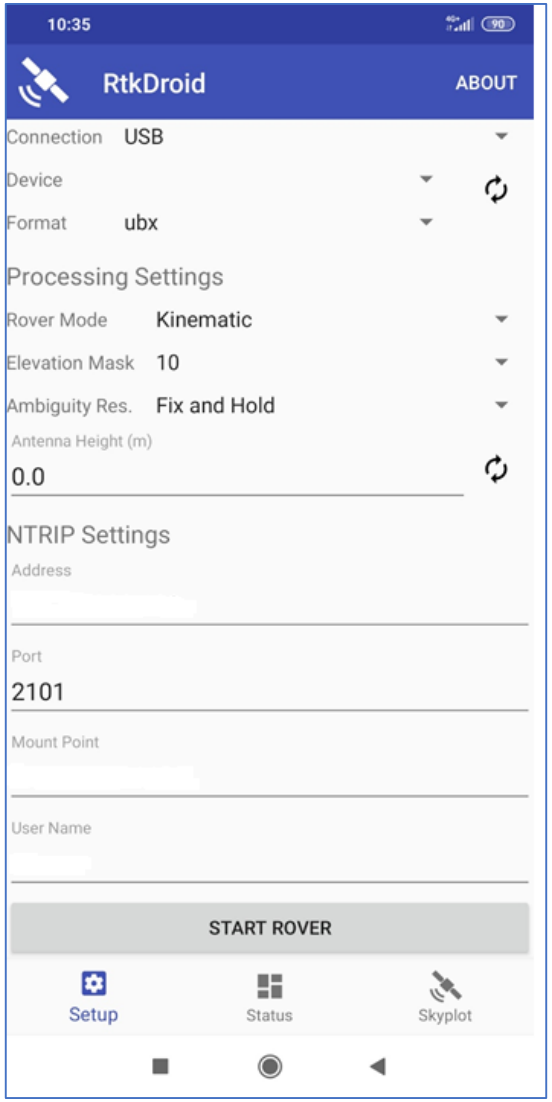
GNSS Receiver Module

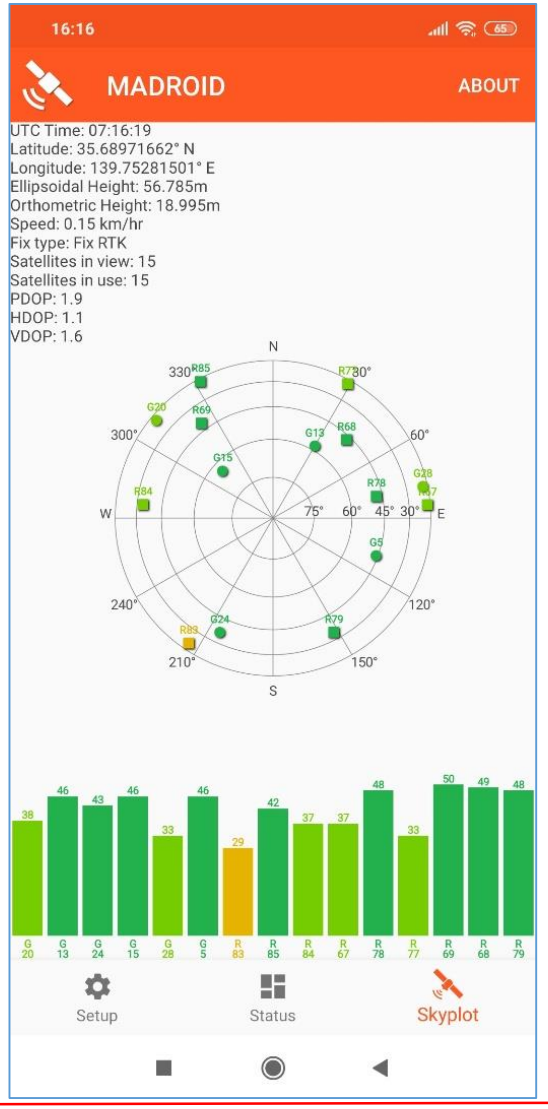
Screen Shots of RTKDROID and MADROID

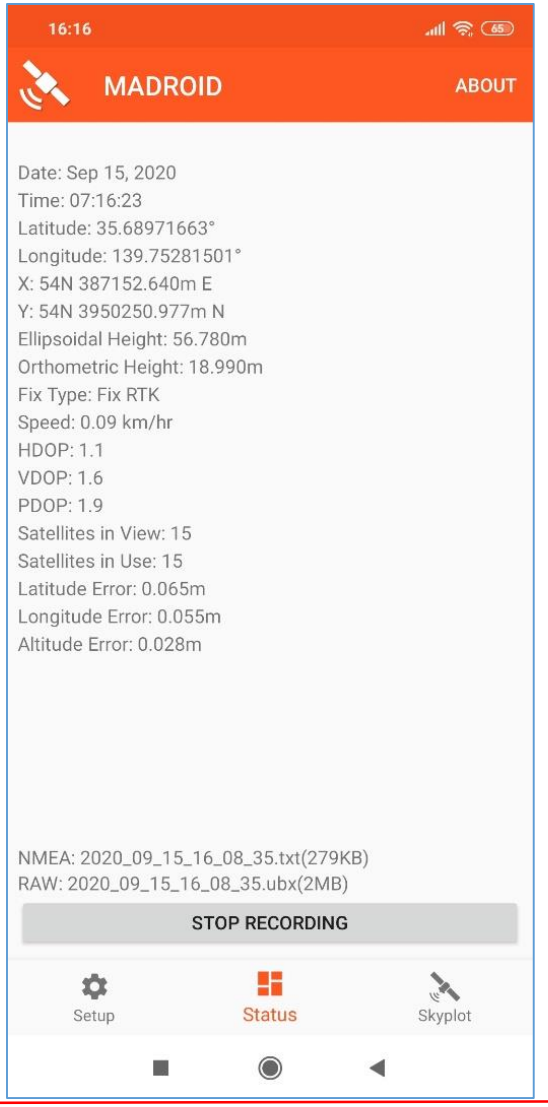
Connect GNSS receiver to Android device

(1) RTKDROID :
For RTK or PPK

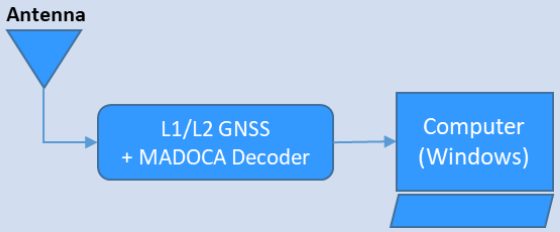
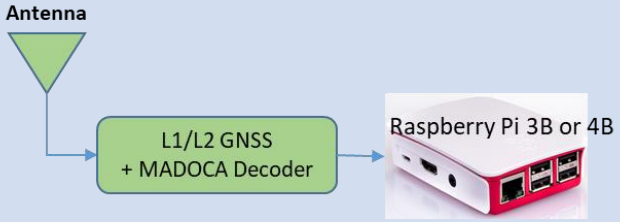
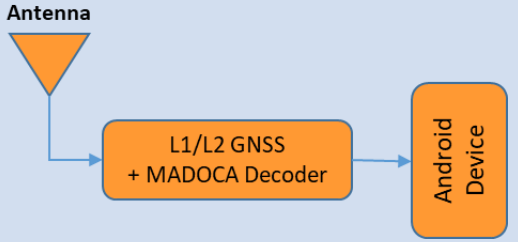
(2) MADROID:
for MADOCA-PPP,
MADOCA-PPP/AR (future)





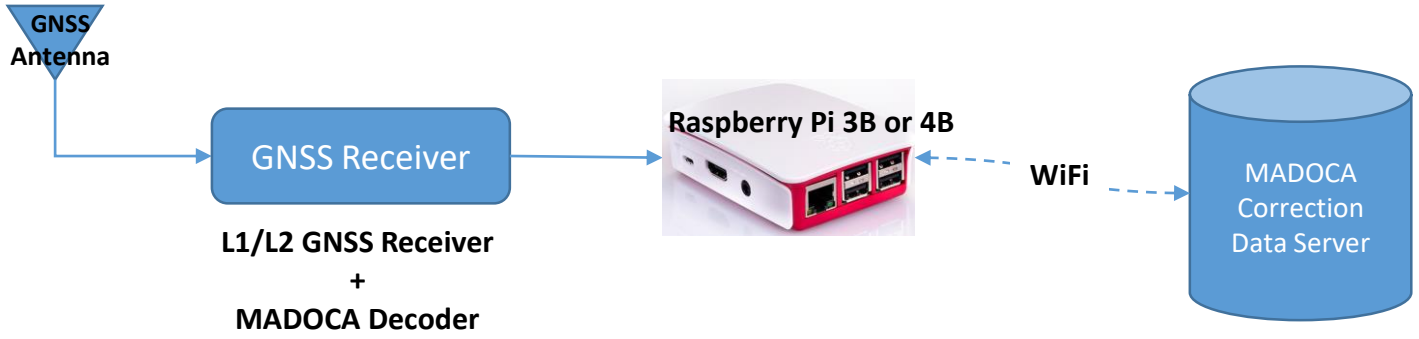


Low-Cost MADOCA Receiver Systems: Product Types

	MAD-WIN	MAD-π	MADROID
Platform / OS	Windows	RaspberryPi 3B or 4B	Android Device
GNSS Receiver	Default : u-blox F9P Other: Any dual-frequency Receiver	Default : u-blox F9P only	Default : u-blox F9P Other: Any dual-frequency Receiver
MADOCA Receiver	U-blox D9 only	U-blox D9 only	NA (MADOCA Online Correction Data only)
GNSS Receiver Data Format	UBX, SBF, RTCM3	UBX SBF, RTCM3 (For online GNSS data)	UBX
MADOCA Correction Data Format (Satellite)	UBX only	UBX only	NA
MADOCA Correction Data Format (Online)	Online Services from GPAS, UTokyo (Test Level) UBX or RTCM3	Online Services from GPAS, UTokyo (Test Level) Online Services UBX or RTCM3	GPAS Services, RTCM3 UTokyo Online Service in the next release
System Architecture			

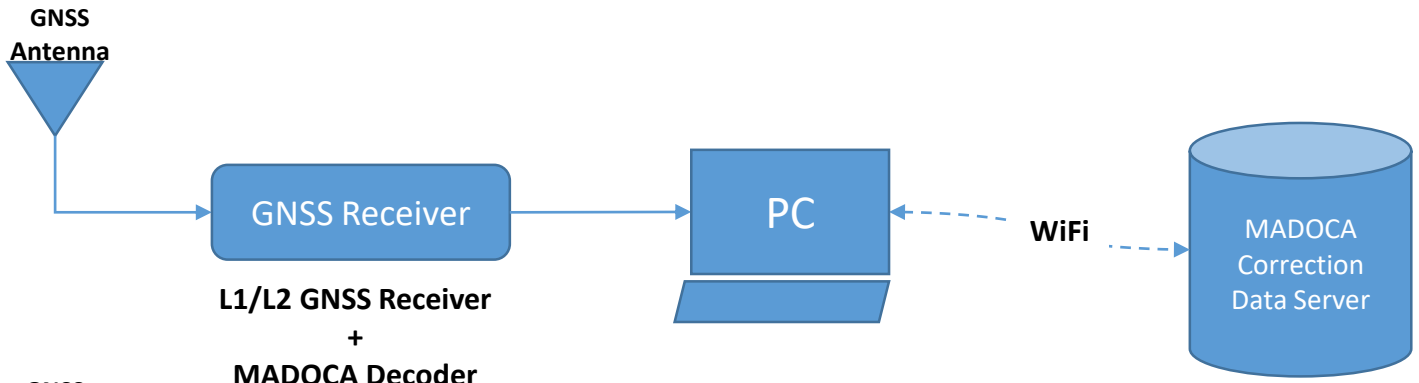
MADOCA Low-Cost Receiver Systems

Type – A : MAD-π



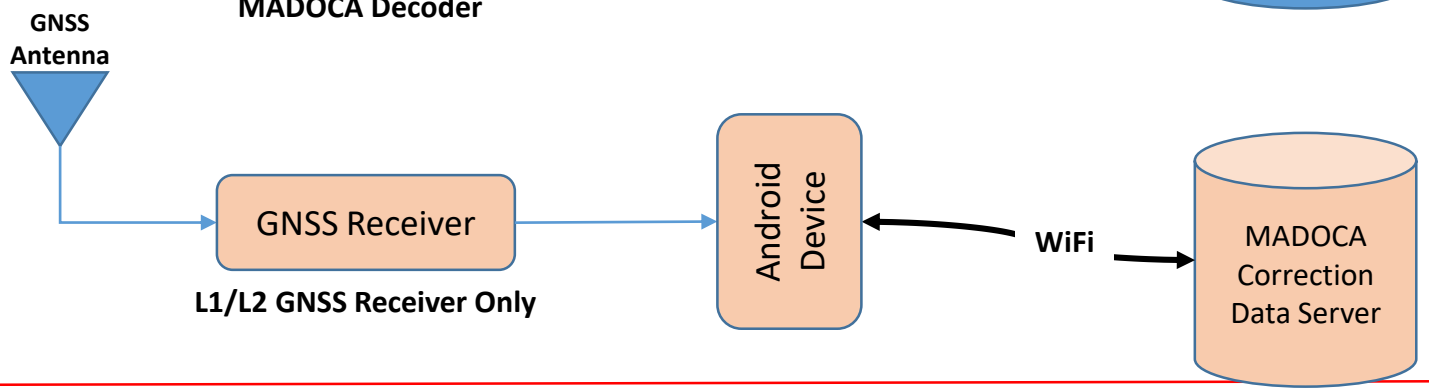
Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

Type – B : MAD-WIN



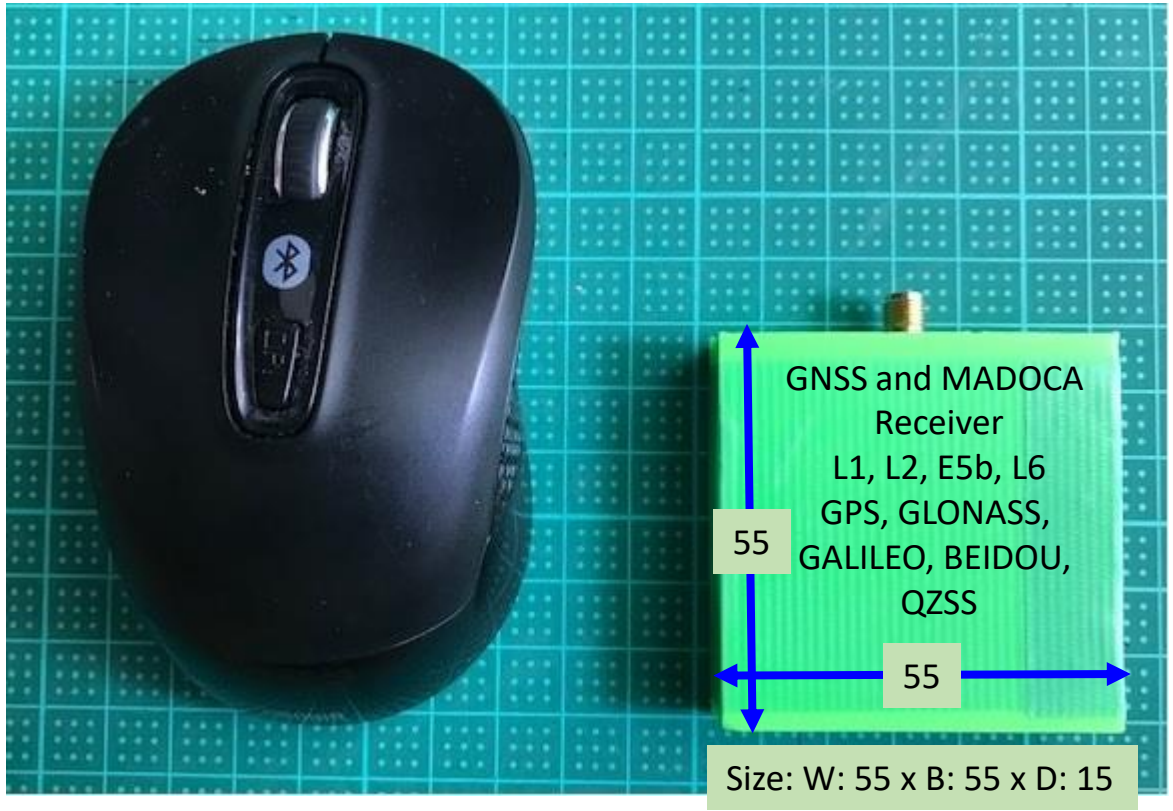
Use MADOCA correction data from server if GNSS receiver does not have MADOCA decoder

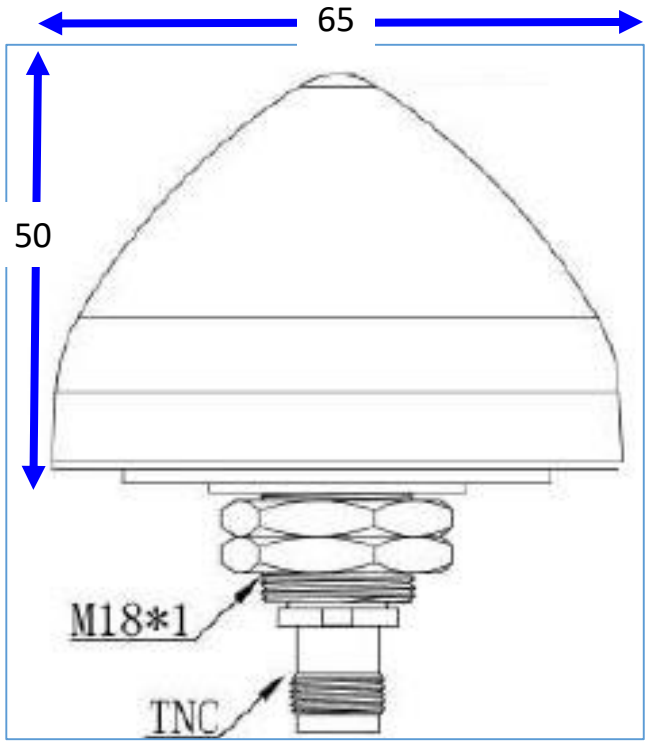
Type – C : MADROID



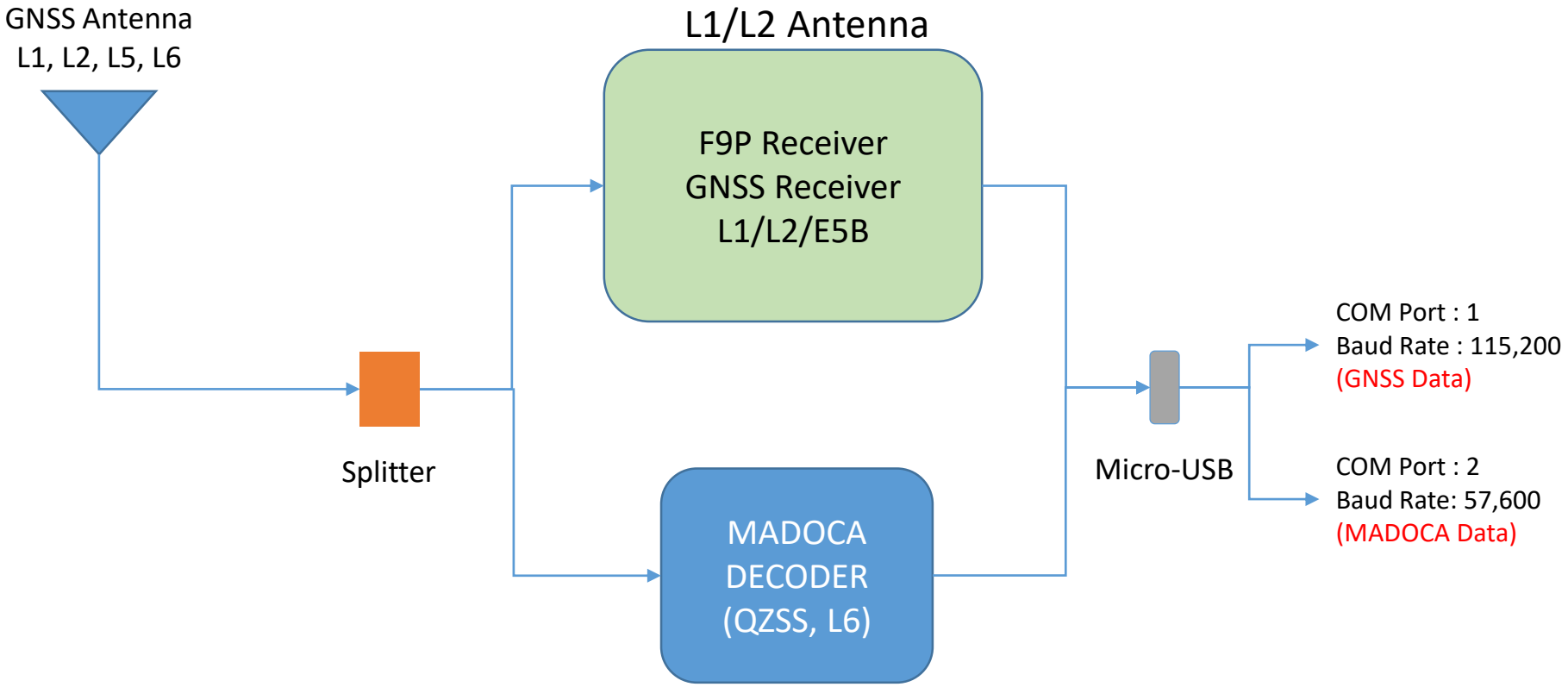
Use MADOCA correction data from server

GNSS MADOCA Receiver and Antenna



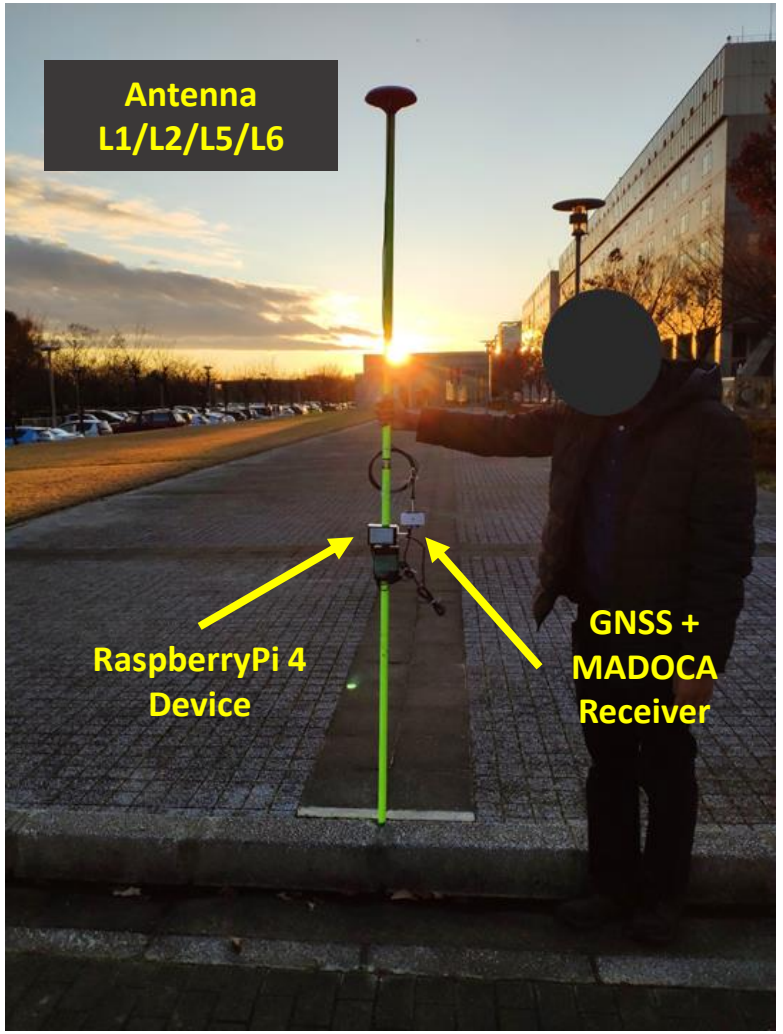


Receiver System Architecture

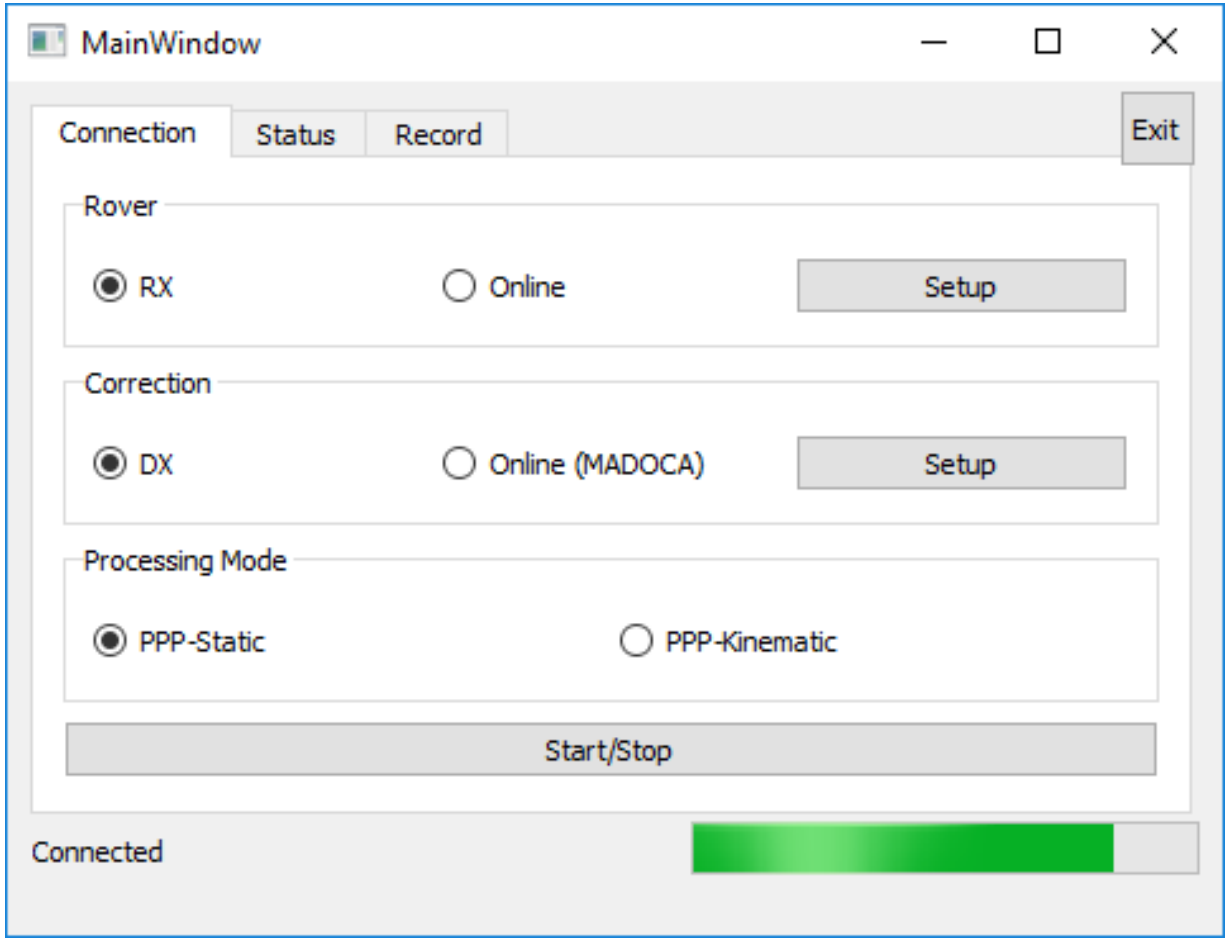


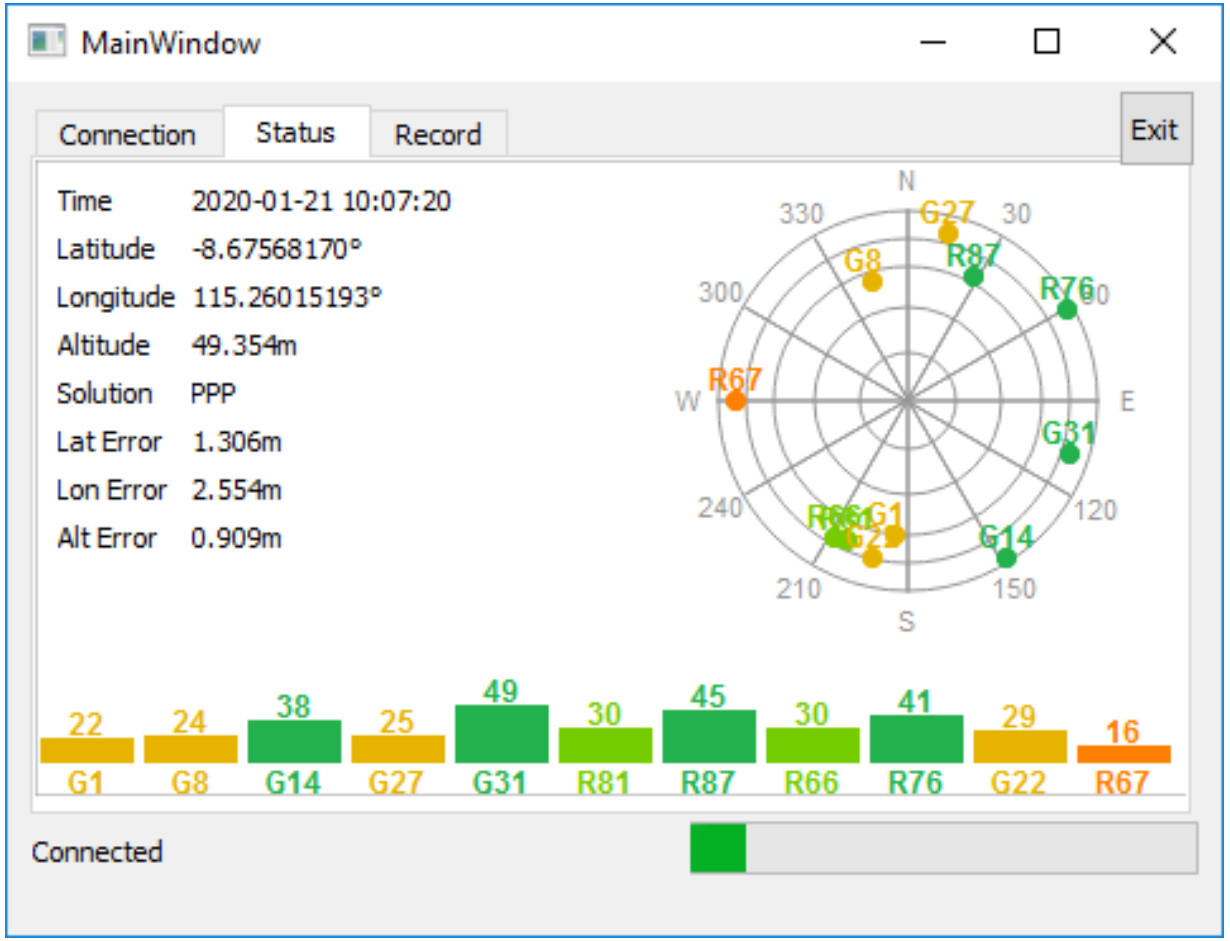
Type A: MAD-PI

MADOCA PPP based on RaspberryPi / Dual Frequency Receiver + MADOCA Decoder



Type B: MAD-WIN

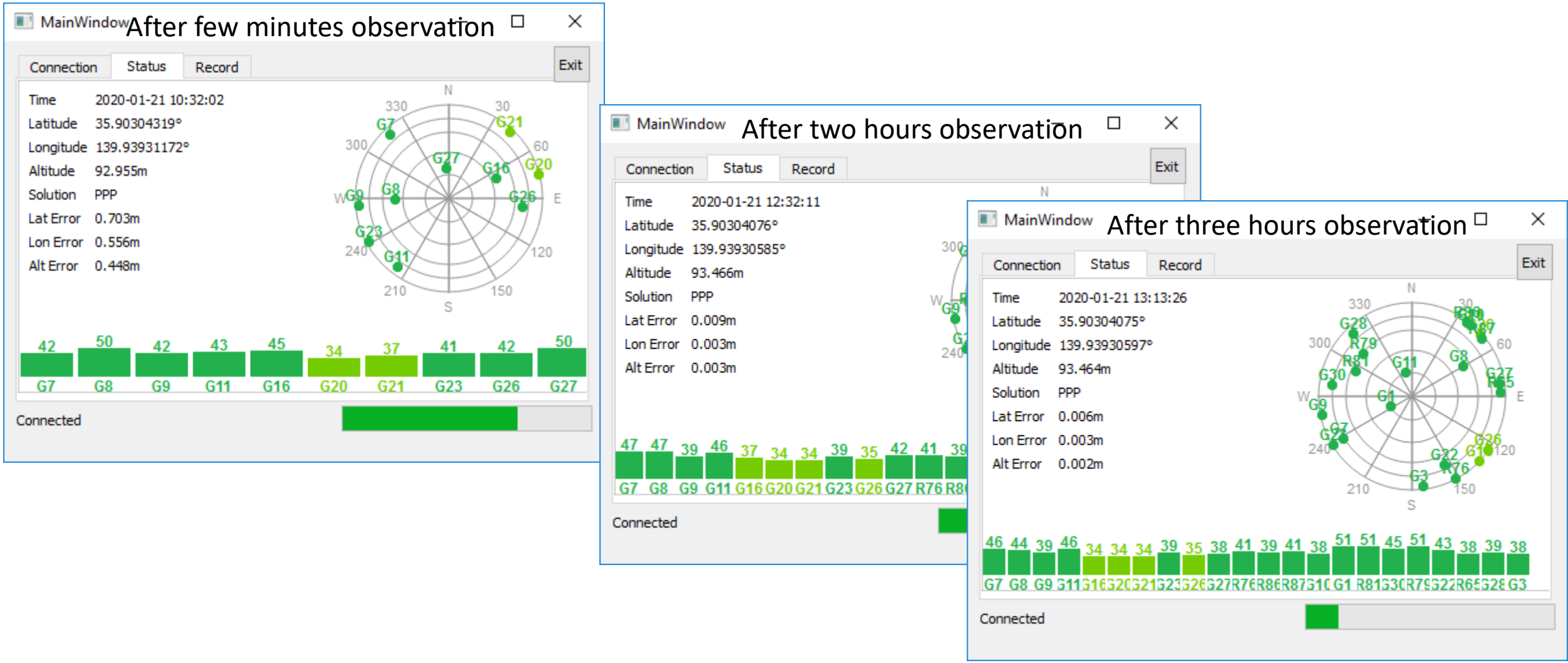




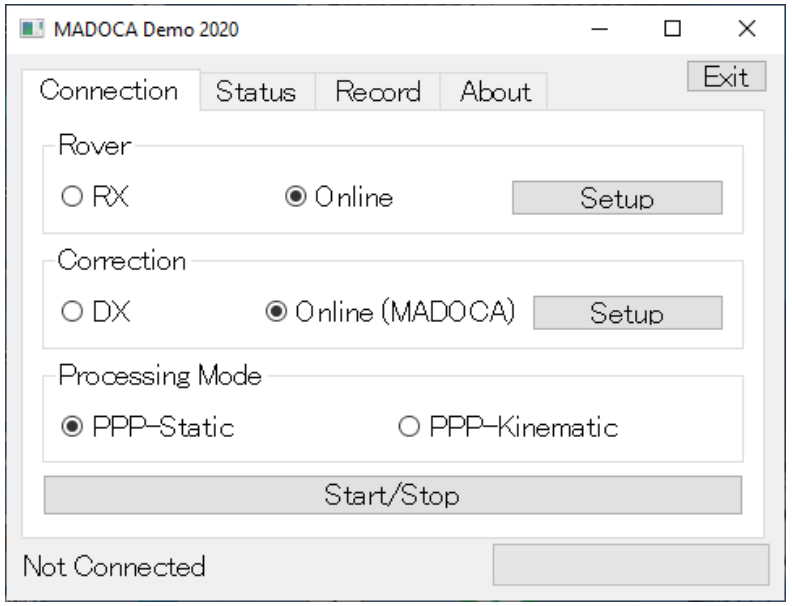
The position accuracy improves to cm (10 – 30 cm) level after initialization time of about 15min.

Type B: MAD-WIN

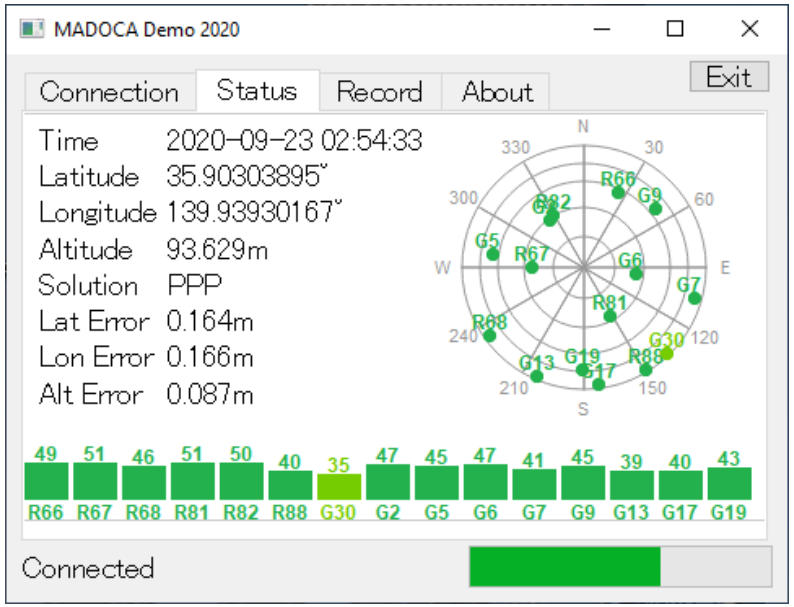
Receiver: Online receiver access in Kashiwa / Correction Data: MADOCA Receiver in Bali



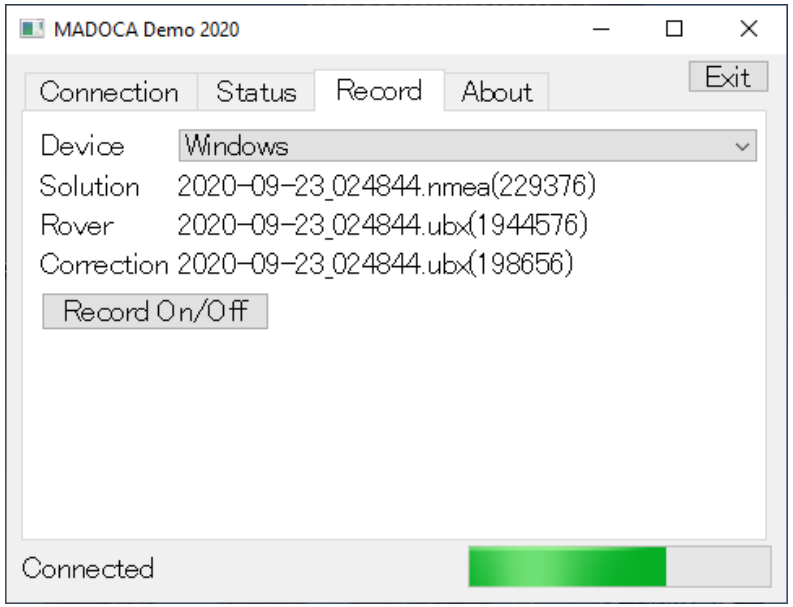
MAD-WIN and MAD-π Screen Shots



Receiver and MADOCA Correction Data Setup Menu



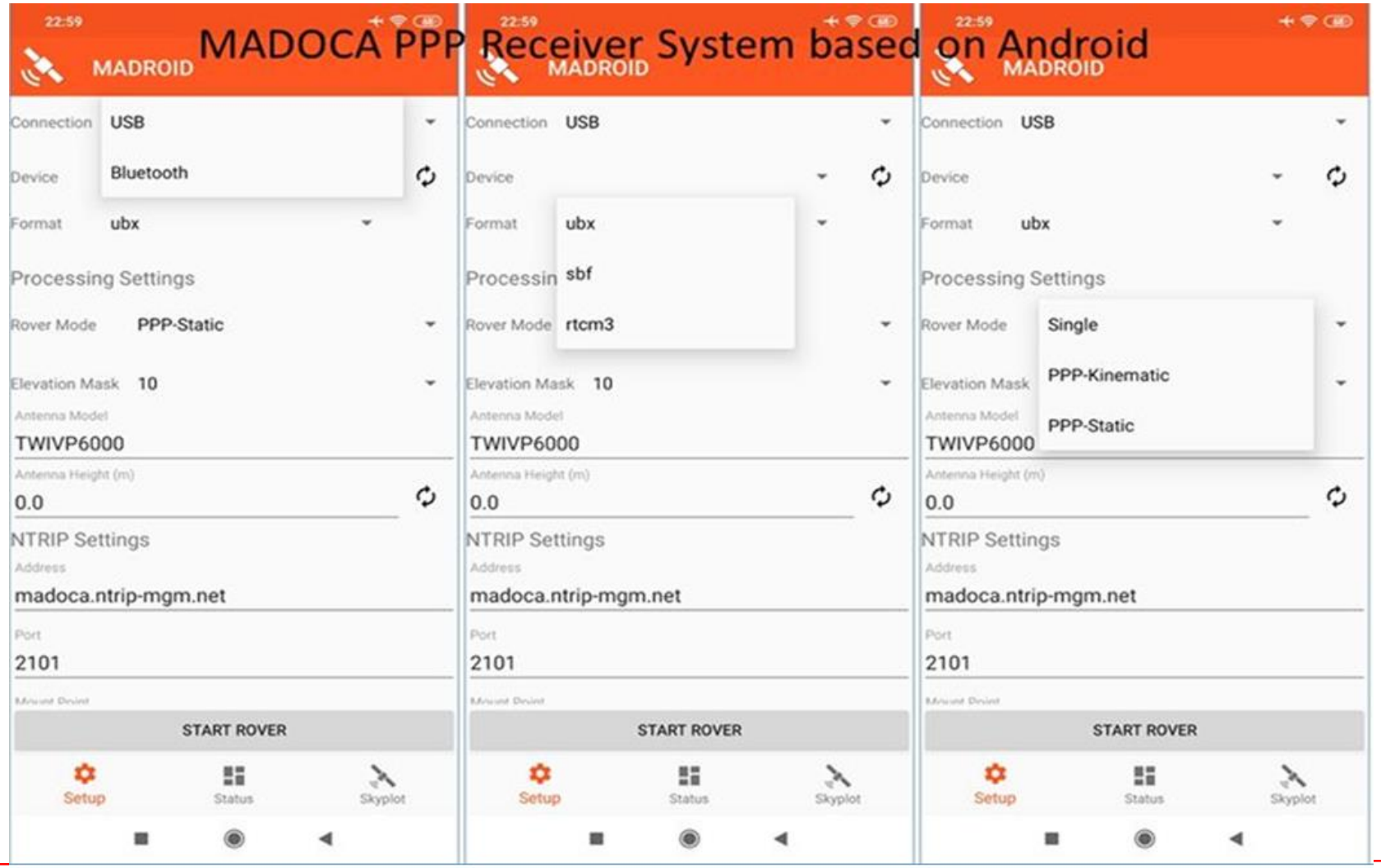
MADOCA PPP Output Display



Log of MADOCA PPP Solution, Receiver Raw Data and MADOCA Correction Data

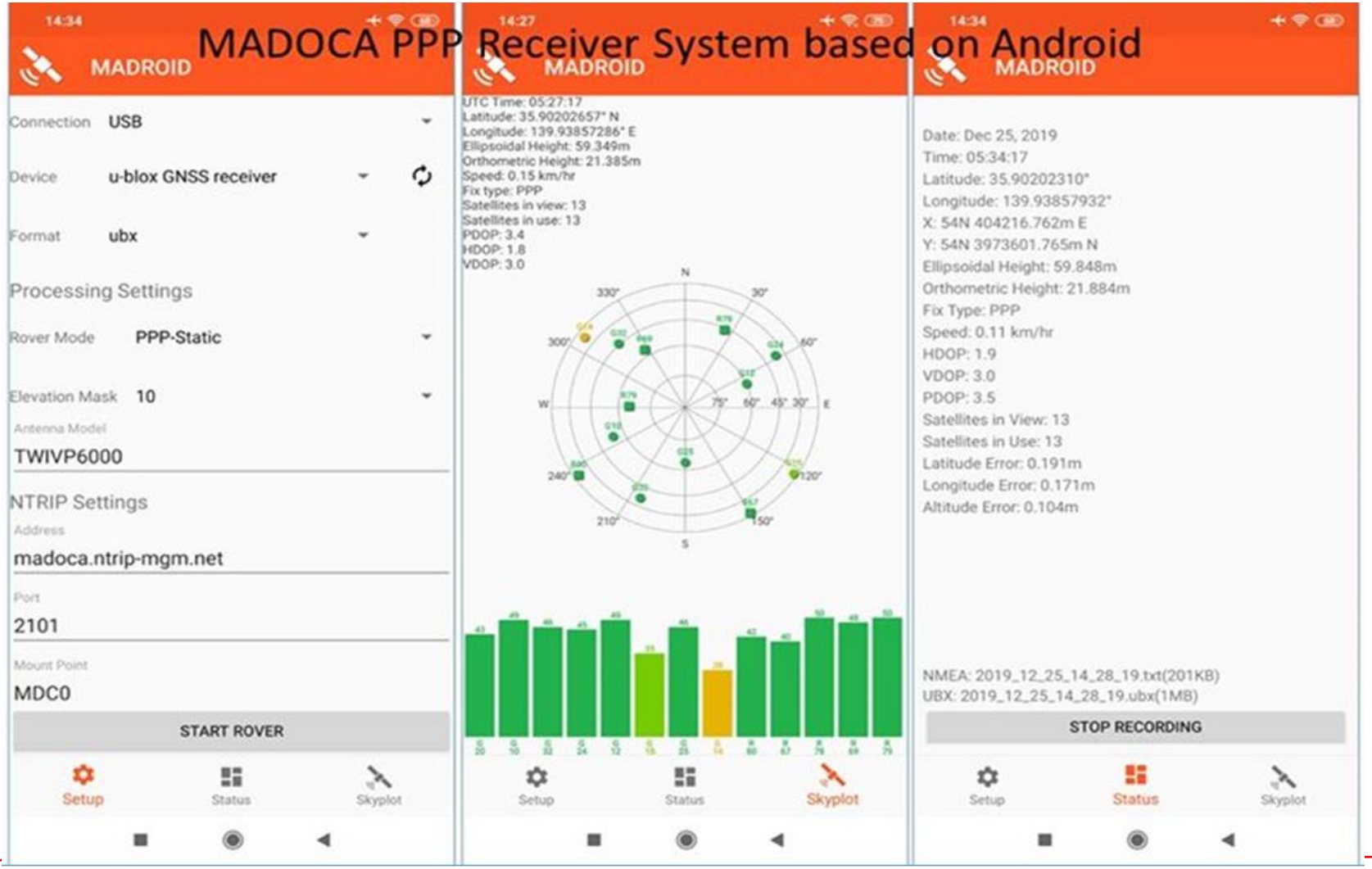
Type C: MADROID / MADOCA PPP based on Android

Dual Frequency Receiver + Online MADOCA Data



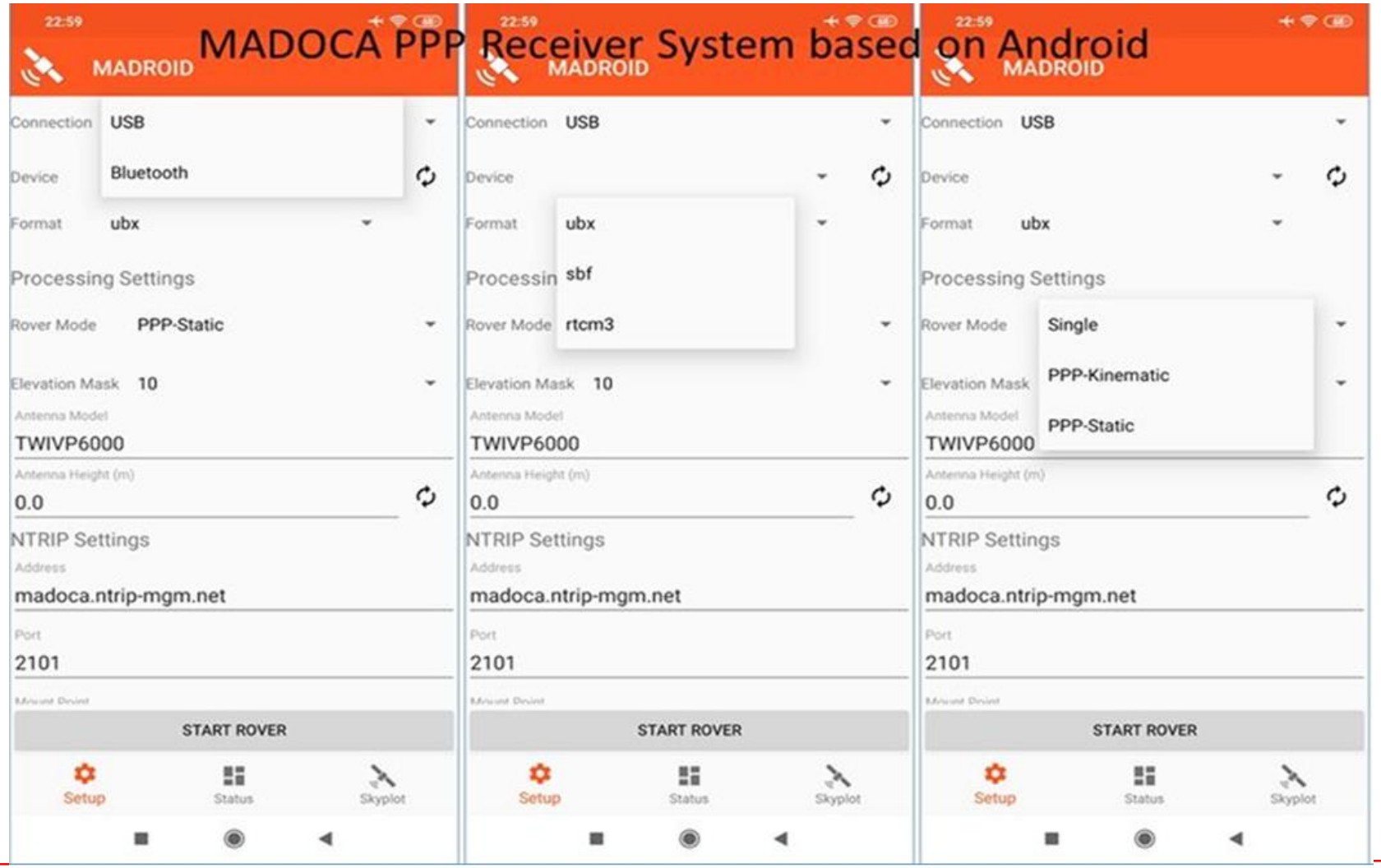
Type C: MADROID / MADOCA PPP based on Android

Dual Frequency Receiver + Online MADOCA Data



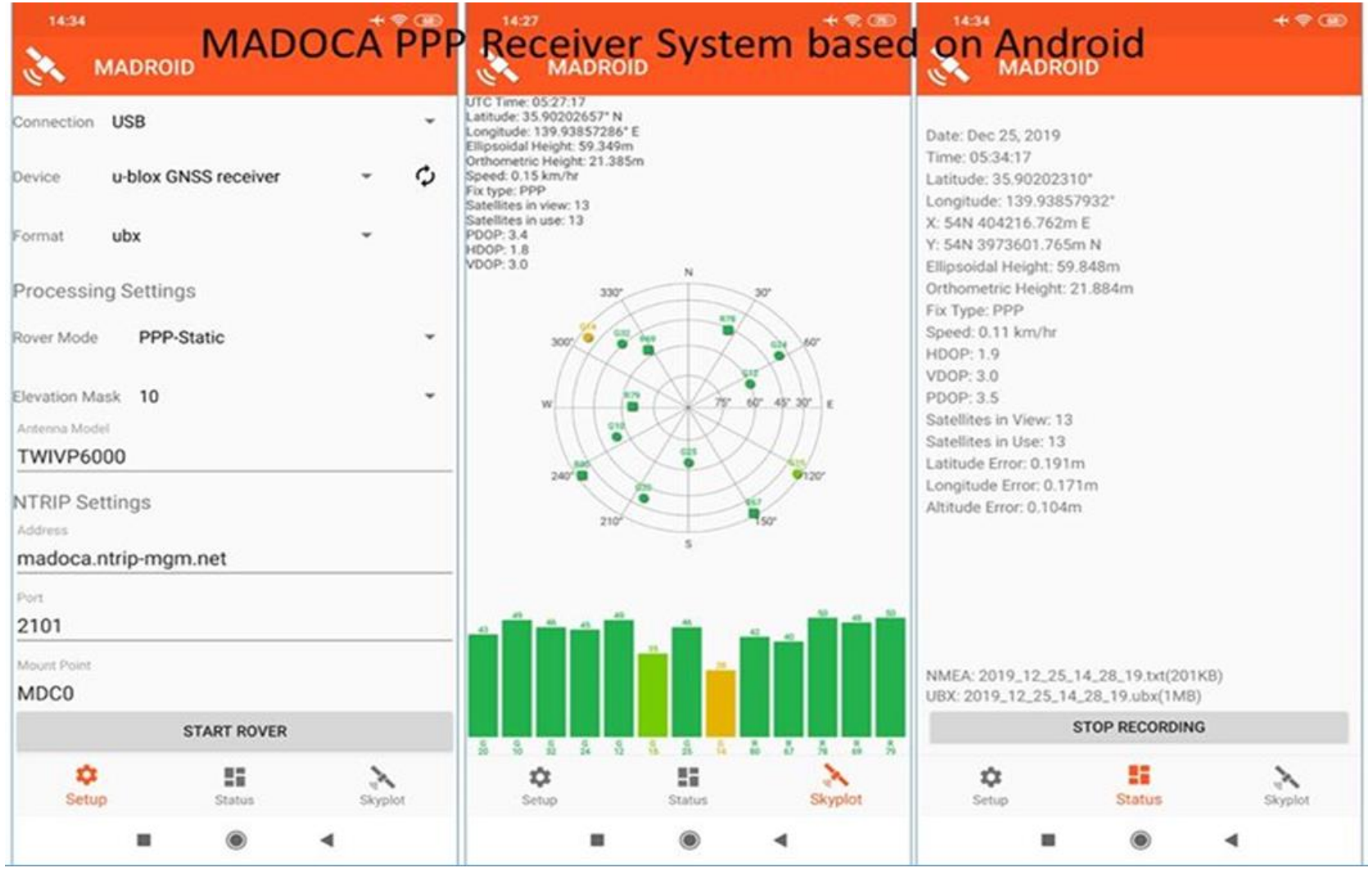
MADROID Screenshots

MADOCA PPP based on Android Dual Frequency Receiver + Online MADOCA Data

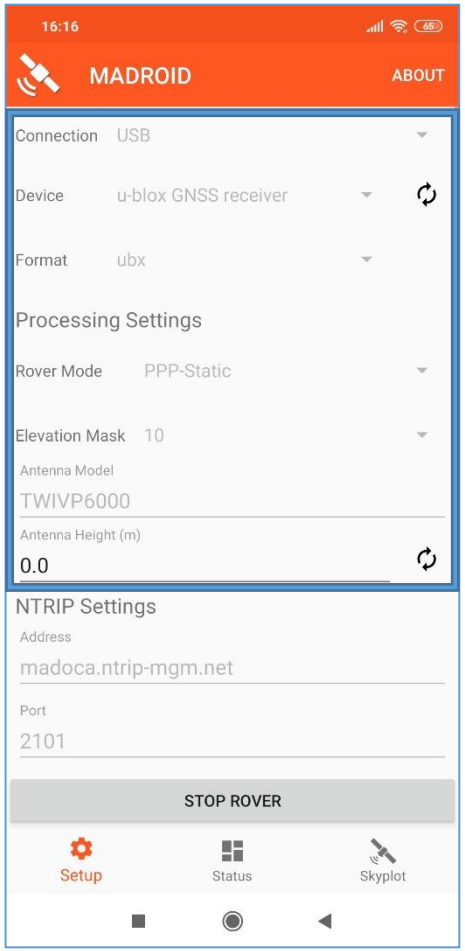


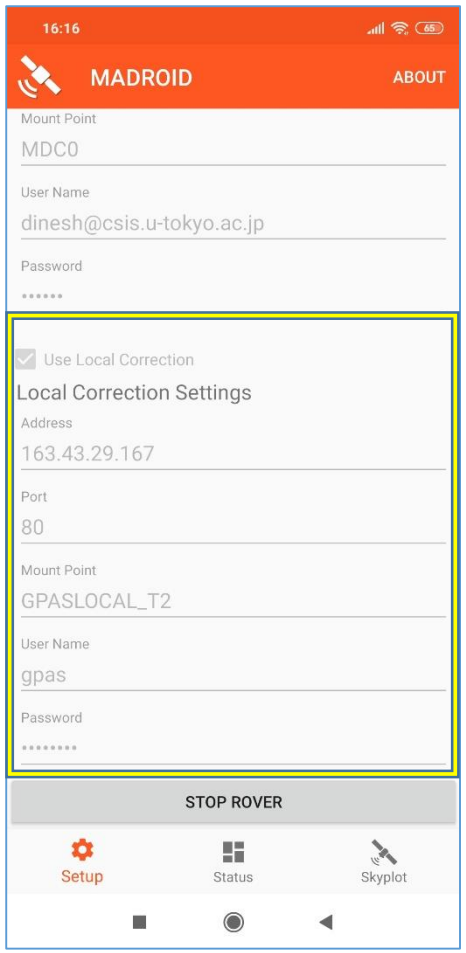
MADROID Screenshots

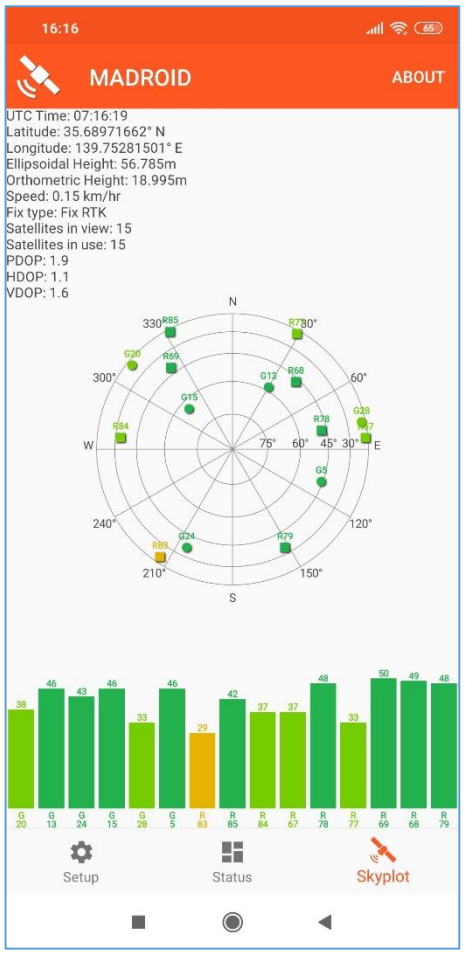
MADOCA PPP based on Android Dual Frequency Receiver + Online MADOCA Data

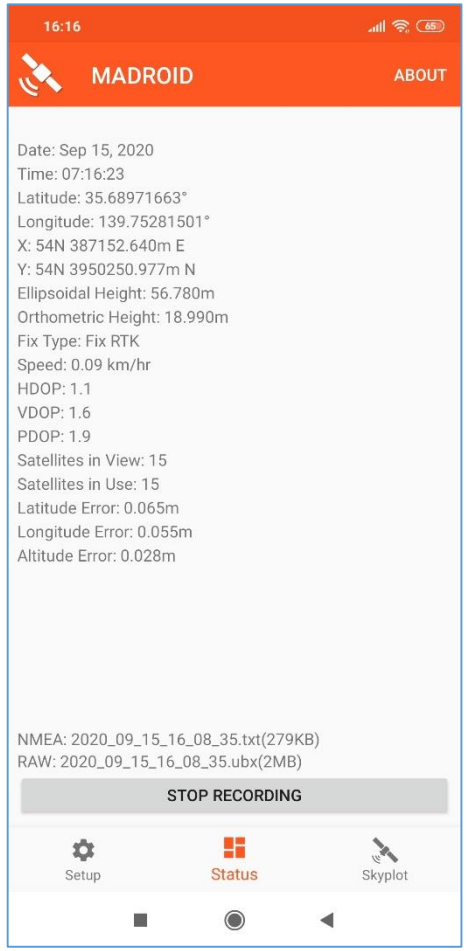


MADROID TEST Results : Tokyo



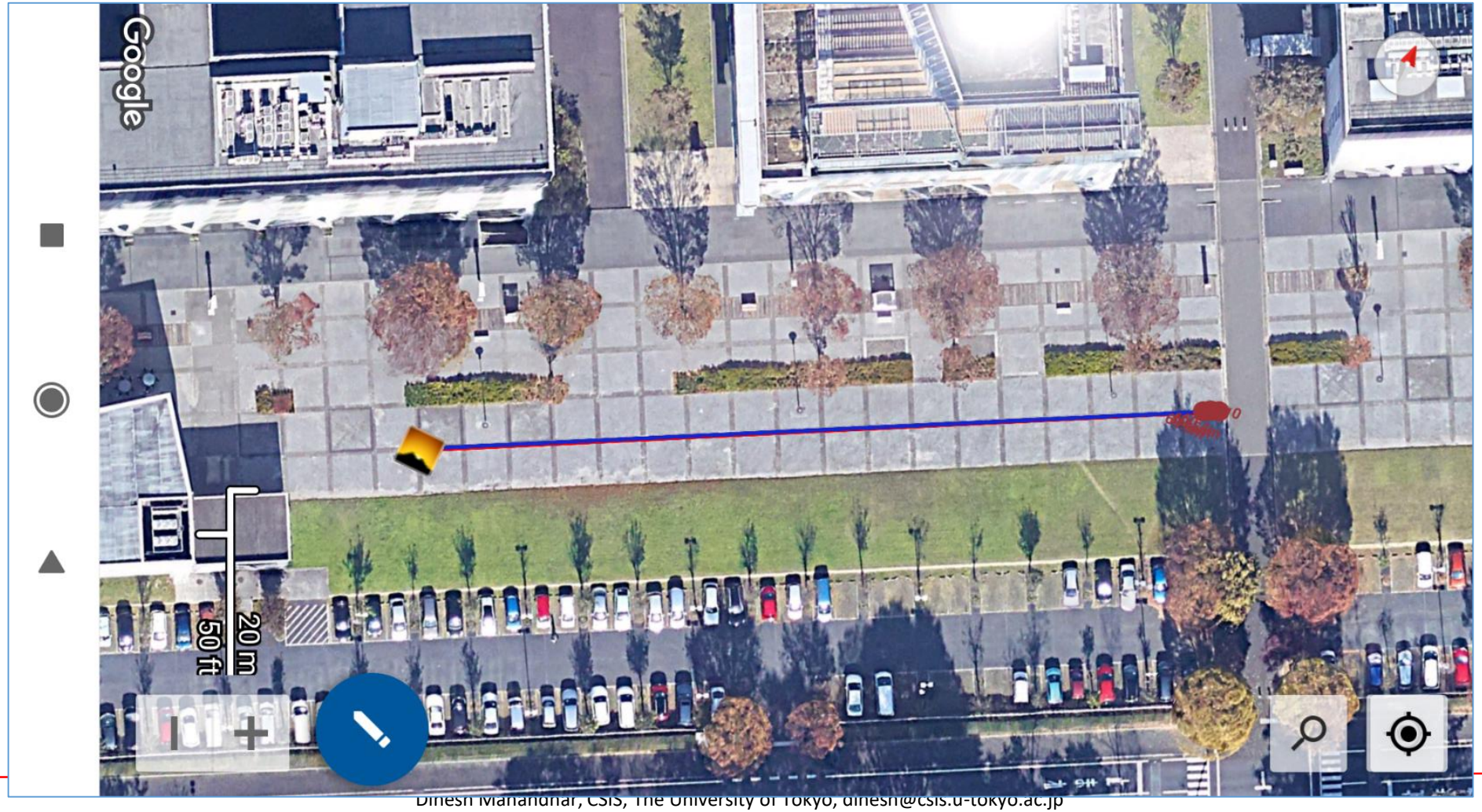






Position Data from MADOCA PPP

We walked straight along the concrete tiles (30cmx30cm) and
PPP results showed perfect straight line. Accuracy is about 15cm.
Receiver : F9 + Online MADOCA Correction Data



Contact and Additional Information

- Homepage
  - Main Page : https://home.csis.u-tokyo.ac.jp/~dinesh/
  - Webinar Page : https://home.csis.u-tokyo.ac.jp/~dinesh/WEBINAR.htm
    https://gnss.peatix.com/
  - Training Data Etc : https://home.csis.u-tokyo.ac.jp/~dinesh/GNSS_Train.htm
  - Low-Cost Receiver : https://home.csis.u-tokyo.ac.jp/~dinesh/LCHAR.htm
  - Facebook : https://www.facebook.com/gnss.lab/
- Contact
  - E-mail : dinesh@csis.u-tokyo.ac.jp
  - Skype : mobilemap